CARBORUNDUM: ITS HISTORY, MANUFACTURE AND USES.

BY

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CARBORUNDUM: ITS HISTORY, MANUFACTURE AND USES.

By E. G. Acheson.

[*Read at the stated meeting of the Institute, held June 21, 1893.*]

For a number of years prior to 1890, I had been keeping a constant watch for anything that might suggest a method by which carbon could be crystallized. A realization of the importance of abrasive materials, in the industrial arts, together with the known superiority of crystalline carbons over all other substances, acted as a constant stimulant to continued exertion for the solution of the problem. In the year mentioned, having become associated with an electric light company, at Monongahela, Pa., I found myself in position to conduct experiments on a line which I had some years earlier formulated. The scheme was to cause carbon to be dissolved in melted silicate of alumina, or in the metals reduced therefrom, and by cooling the same to the point of solidification, cause the contained carbon to crystallize. You have heard that "fools rush in where angels fear to tread," and had I been a chemist, it is probable that such an experiment would not have been thought worthy of consideration, and certainly would not have been attempted. Be this as it may, the experiments were made with results more or less satisfactory.

The first experiment was with a furnace constructed of an iron bowl lined with carbon, in the central cavity of which was placed a mixture of carbon and clay; through the mixture was passed an electric current of sufficient amount to fuse the mass—a violent reaction following the fusion—the iron bowl, and a rod of carbon suspended in the centre of the mixture, forming the electrodes. After the mass had cooled, it was removed, broken and carefully examined, when a few bright crystals, blue in color and apparently very hard, were found to be in that part which immediately

surrounded the carbon electrodes. They were exceedingly small and only served to convince me that more and better arranged experiments would produce the desired results.

The iron bowl furnace was replaced with one constructed of refractory bricks, its interior dimensions being 10 inches in length by 4 inches wide and 4 inches deep. Into each end extended a carbon rod, so arranged as to be movable in the direction of its length, thus allowing of a variation of the distance through which the current would have to traverse the charging mixture. The electrical apparatus was arranged for supplying and regulating a current of from 100 to 200 ampères, and of an adjustable potential of from one to fifty volts. The current used was an alternating one, and the action and effects produced were thereby reduced to one of temperature, the probability of electrolytic effects not existing.

The first experiments were confined, more or less closely, to the original lines, as defined by the theory with which I commenced—carbon and clay forming the basis of operation. It was soon discovered that the crystals were not what I had expected to obtain—they were not pure carbon; in color they were usually blue, and their hardness was found to be sufficiently great to abrade the diamond. They seemed, however, to be exceedingly brittle, and it was only in the form of a very fine powder that they were capable of performing this work. Repeated attempts to charge the surface of a copper, or other metallic disc, were productive of failures, as compared with the results obtained with crushed diamond under similar conditions; the crystals being too brittle to withstand the pressure necessary to embed them, or in case of their being embedded, they would be broken and crushed when subjected to use in the manner of the well-known diamond saw.

At this point in the work the want of a name for the new product was felt. It had not been analyzed, and I was led to believe, from the materials used, together with the color, sapphire blue and ruby-red, hardness and general form, that the material was composed of carbon and alumina, and in this belief it was decided to construct the name of the new

material out of carbon and corundum, and it was named carborundum. The fitness of the name, in the eyes of the chemist, is, in view of the now known composition of the substance, doubtful, while in commerce, although phonetic and of pleasing effect in print, it is, perhaps, a trifle lengthy.

I had not continued my experiments long, before certain conditions and results obtained, led me to think the silica present in the furnace played a very prominent part in determining the quality and quantity of the carborundum; and with a view of determining whether or not this was the case, a mixture was made composed of carbon, silica and chloride of sodium; my former experiments having proven the presence of common salt to be beneficial, facili-

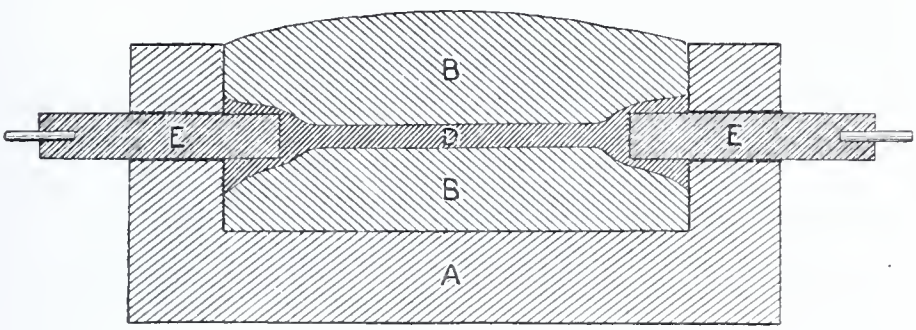

FIG. 1.—Longitudinal section of furnace.

tating the fusion, and to some extent protecting the mass in the furnace from oxidation by air contact. The carbon used was obtained from the carbon rods used in arc lamps, they having been reduced to a powder. These carbons had been made from the coke residue obtained in the distillation of petroleum. The silica was of a good grade of glass sand, its composition not being known. The salt was a good average quality. These materials were mixed in the proportion of forty per cent. each, of carbon and sand, and twenty per cent. of salt, and the mixture was placed in the furnace.

I had met with considerable trouble in operating the furnace from the difficulty in starting the fusion of the mixture, and the continual changes that occurred in the

internal resistance; the contacts, or connection between the electrodes and mixture, were also very difficult to maintain. To obviate or reduce these objectionable features, the connections and chargings were made in the manner shown in the diagram, where *A* represents the walls of the furnace, *B B* the mixture of carbon, salt and sand, *E E* the carbon rods or electrodes, and *D* a core of granular carbon, this core being enlarged at its extremities and made to surround the ends of the electrodes.

The furnace having been prepared in this manner, the electric current was made to pass. The value of this current was never constant, thus: on starting it would have a value of about forty ampères, with a potential of about fifty volts; the ampères would immediately increase, the potential being kept constant until the limit of the apparatus, or 200 ampères, had been reached, at which point the regulation of the potential would begin, finally stopping at about twenty-five volts, the ampères remaining at 200. These changes were produced, on the part of the current quantity, by a reduction in the resistance of the furnace due to the increasing temperature of the core and mixture, fusing of the salt, and eventually to the formation of a black material, consisting of a mixture of carborundum and free carbon, this material having a high conductivity. The reduction of the potential was produced by the ordinary methods of regulation, and was made to prevent the continued increase of the ampères and consequent burning out of the generating apparatus.

An experiment was made with the mixture, arrangements of charge and current as stated, the time required being about four hours. The mass heated slowly, the first outward indication of the internal heat and reactions being the appearance of monoxide of carbon, which was lighted and continued to burn during the remainder of the experiment; later, occasional bursts of white vapors of chloride of sodium would occur, and these would be followed by a flow of melted chloride of sodium, forming miniature volcanic craters.

The action was continued until there was a cessation of

these disturbances, until the blue flames of burning monoxide of carbon became tinged with a deep yellow from the sodium, and until the reduction of the potential indicated a low resistance, resulting from the formation of the black substance above referred to; the current was then stopped, and the furnace permitted to cool and opened.

A representation of the cross-section of the furnace when opened is shown in *Fig. 2*, where *A* represents the walls of the furnace; *B*, the mixture of carbon, sand and salt, now a solid cemented mass consisting of sand and carbon held together with the fused salt; *D*, the carbon core, and *G C* and *W*, zones of portions of the original mixture *B*, now transformed into materials of variable composition.

The results obtained from the first experiments with a

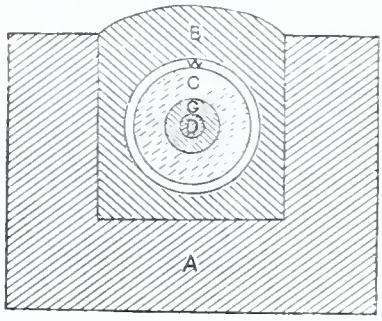

FIG. 2.—Cross-section of furnace.

mixture containing silica, instead of silicate of alumina, were so much superior to the results formerly secured, that the use of clay was abandoned.

Such is a brief sketch of the first manufacture of carborundum. Its further development and present manufacture form a large portion of the history of the Carborundum Company.

The results obtained were so promising that it was thought a lucrative business could be made of the manufacture and marketing of carborundum, and acting on this belief, a company was organized for these purposes. The processes of manufacturing carborundum and the working of it up into marketable form, were elaborated, and up to the present time are undergoing changes and improvements.

One of the first acts of the company was the equipment of a chemical laboratory, and the engagement of Dr. Otto Muhlhaeuser, who entered at once into an exhaustive analytical study of carborundum. The results of his labors might be briefly stated as follows:

A sample of carborundum, as originally made from carbon, clay and salt, and having, to the unassisted eye, a blue-black color, but under the miscroscope exhibiting a few crystals of a yellow-green color, some black, some white, with the majority blue, gave the following:

Si,	60·51
C,	30·09
Al_2O_3,	4·78
CaO,	·17
MgO,	·18
O,	4·27
	100·00

A sample of carborundum, made from carbon, sand and salt, having a clear light-green color, gave as its composition:

Si,	69·19
C,	29·71
Al_2O_3 and Fe_2O_3,	·39
CaO,	·19
MgO,	·06
O,	·47
	100·00

From these figures we learn that what we have called carborundum is, in a pure state, carbide of silicon, responding to the formula SiC, the other substances being impurities. The carbon used in the manufacture of the last sample—the one from sand—was obtained from the coke of bituminous coal, and by it the iron was introduced which we find in the analysis.

The great difficulty met with in obtaining a complete combustion of the carbon, necessitated the reduction of the sample to the finest powder; the samples used for analysis being obtained by floating in water for some minutes, thus

permitting the coarser particles to fall down and be separated from the finer. This latter portion, remaining in suspension in the water, was decanted into another vessel and permitted to settle for some longer period. The degree of fineness of the powder is then indicated by the number of minutes it stood in the first vessel. The necessity for this minute subdivision is shown by the following percentages of carbon as determined from powders of different degrees of fineness, all of them forming part of one original sample:

	Per Cent. C.
Crushed crystals,	24·82
One minute,	25·08
Two minutes,	27·06
Three minutes,	28·04
Four minutes,	29·71

The wonderful permanency of carborundum, when exposed to a high temperature, is also shown by the fact that clean and pure powder heated to bright redness in a current of oxygen for a period of one hour lost only ·41 per cent.; this same quality is also shown in the following determination of silica (SiO_2) formed by the ignition of carborundum (SiC) crystals in the open air in a platinum crucible at a bright red heat for ten hours:

	Grs.
Weight of crucible,	28·5315
Weight of crucible and SiC,	29·0362
Weight of crucible and SiC after ignition,	29·0220
Loss,	·0142
Weight after ignition,	29·0220
Weight after treating with HF and H_2SO_4,	29·0082
SiO_2,	·0138
Total loss,	·0276
Weight of SiC at first,	·5047
	Per Cent.
Total loss,	5·5
Loss per hour,	·55

While the effort is always made to produce carborundum as nearly pure as possible, the conditions of its manufacture are such as to cause a larger or smaller percentage of

impurities to be present. It is, of course, impossible to use a mixture of carbon and silicon as represented in the composition of carborundum, an excess of carbon must be present at the beginning of the process to take up to oxygen present and entering from the air. It has been found that a very good proportion for the mixture is twenty parts carbon, twenty-five parts sand and ten parts salt (by weight). A sample of carborundum made from this mixture was tested for silica (SiO_2) and a treatment for eight days with hydrofluoric acid (HF) showed the amount present to be 1·56 per cent.

Before entering upon a consideration of the commercial features of carborundum, I will present the following condensed report of the investigations of Dr. Mulhaeuser, as prepared by him at my request for this paper.

The structure and chemical composition of the mass after the reaction was found to be as follows, reference being made to the diagram, *Fig. 2*.

D represents the path of the current, the core of carbon connecting the terminals forming with the latter the resistance by which the electrical energy is transformed into heat energy. This core shows—after the reaction—no change.

G represents a shell of a brilliant black mass which surrounds the carbon core; it consists of crystalline-like aggregates, which are arranged radially to the axis of the core. The part near the core consists of pure carbon, those parts more distant from the axis of the core are more or less mixed with carborundum crystals. A sample of that part gave, for instance, the following analytical results:

	Per Cent.
Free carbon,	66·29
Carborundum,	33·71

The free carbon has all the properties of graphite, it blackens the fingers, etc. The carborundum found in this zone *G* gave the following numbers:

	Per Cent.
C,	30·49
Si,	68·26
Fe_2O_3,	0·77
CaO,	0·48

To separate the carbon from the carborundum the mass is heated with hot oxygen. The crystals obtained in this way, though they possess generally the properties of carborundum, seem to differ a little in their optical qualities. They show, after having been freed from carbon, all the colors of the spectrum; especially brilliant are the red and violet rays.

C represents the chief product of the reaction, the zone of the carborundum, chemically spoken of as crystallized carbide of silicon. The zone of carborundum surrounds the graphite zone. The crystals are arranged radially to the axis of the core, and form in general a bright green shell. For the purpose of analysis, a sample of that shell was reduced to a powder of the proper fineness and gave the following figures:

	Per Cent.
Si,	62·70
Fe_2O_3 and Al_2O_3,	0·93
MgO,	0·11
C,	36·26

This analysis showed clearly that carborundum consists essentially of carbon and silicon associated together in the proportion of one atom each. In order to clean the product, to free it from iron, aluminum, etc., the powder was treated in the following manner: First with hydrochloric acid, then with dilute caustic soda and water, then the powder was put in a combustion tube, heated to dark redness and a current of oxygen passed over it for about one hour. All free carbon and perhaps a little of the combined carbon is burned off and a powder obtained, which contains now only silica, acid, traces of magnesia, alumina and iron, besides the carbide of silicon. By treating the powder with hydrofluoric acid, the carbide of silicon is obtained nearly pure. One of the many samples cleaned in this way, gave the following results:

	Per Cent.
Si,	69·10
C,	30·20
Al_2O_3 and Fe_2O_3,	0·49
CaO,	0·15

A compound having the formula SiC contains seventy per cent. Si and thirty per cent. C.

If pure carbon and pure silicic acid be taken the carborundum crystals will be white; if these materials contain iron, the crystals show a greenish-yellow color.

The crystals are not dissolved either by hydrofluoric acid or by any other acid; they are slightly attacked by dilute caustic and carbonated alkalies; and they are decomposed by caustic or carbonate of soda by fusion. The carbon is separated and silicon is transformed in silicic acid, the whole mass becomes black, then after some time the carbon burns off.

When reduced to a very fine powder and floated in water, carborundum does not settle, even after a period of months, It behaves like a colloidal substance, for instance metallic silver. By adding an acid or a salt, the extremely fine powder settles.

IV represents a white or gray-greenish looking shell, surrounding the zone of carborundum crystals. The mass consists of small pieces of the size of the original sand grains. These pieces are soft and may be reduced very easily to a fine powder. The qualitative analysis showed that the powder had the same constituents as the carborundum crystals, and the powder was, therefore, cleaned in the same manner as in the case of those crystals. The white-green shell was crushed and alternately heated with hydrochloric acid, caustic soda, water, hot oxygen and hydrofluoric acid. The resulting powder had the following composition:

	Per Cent.
C,	27·93
Si,	65·42
Fe_2O_3 and Al_2O_3,	5·09
CaO,	0·33
MgO,	0·21

We may say then, that the powder consists essentially of carbide of silicon. But this carbide of silicon is different from the other one in that it forms no crystals, is amorphous and very soft, and of no value as an abrasive. It has been obtained at a comparatively low temperature—far distant

from the core—and is identical with the product recently obtained by I. Schützenberger.

B represents the less attacked mixture of sand, carbon and salt. This mixture surrounds the other shells. An analysis of a sample taken from the top of the mass gave the following composition:

	Per Cent.
(I) Salts soluble in water,	11·19
(II) Carbon, free,	32·96
(III) Ash (insoluble in water),	55·85

The analysis of part I gave the following results:

	Per Cent.
P_2O_5,	0·02
SO_3,	2·43
MgO,	0·04
CaO,	0·19
Al_2O_3,	0·04
Fe_2O_3,	0·71
NaCl,	96·57

Part III had the composition:

	Per Cent.
SiO_2,	94·28
Fe_2O_3,	1·75
Al_2O_3,	4·24
CaO,	0·21
MgO,	0·14

The composition of this—the outer mass—would, however, be a variable quantity, depending upon the original mixture.

While it is not my intention, nor the purpose of this paper, to enter into any exact statements regarding the cost of manufacturing carborundum, I deem the subject one of sufficient interest to justify some few remarks and figures.

The quantity produced at the present time will average 150 pounds per day of twenty-four hours, requiring an expenditure of seventy-eight horse-power for a like period, or 1,872 horse-power hours, amounting to twelve horse-power hours for each pound produced. Improvements now being introduced, relating to the design of the furnace and current regulations, will, it is expected, reduce this expendi-

ture about twenty per cent. or thirty per cent. The location of the works—in the centre of the great coal fields of Western Pennsylvania—permits of obtaining cheap fuel, for the steam plant, and cheap coke for the use of the carborundum furnaces. The value of this location is not, however, of so great significance at the present time, as it will prove to be with largely increased production, for, while with an output of 150 pounds per day, the fuel constitutes but one-third of the total cost of the power, with an output amounting to ten times that amount, or 1,500 pounds, it would be approximately two-thirds of the cost. The present practice entails a loss of a considerable quantity of the coke, sand and salt, used in charging the furnaces; the amounts required for producing one pound of carborundum being, approximately, four pounds of mixture containing 1·82 pounds of sand, 1·46 pounds of coke, and ·72 pound of salt. Much of this waste is due to difficulties encountered in re-using portions of the mixture left from former charges, this applies particularly to that portion designated in the diagram as *W*, and that portion of the mixture *B* immediately surrounding it.

The furnace as now used does not materially differ from the early form as shown in the diagram. The advisability of furnishing a ready escape for the gases produced, together with the necessity of having refractory and electrically non-conducting walls, has resulted in the continued use of fire-brick for its construction. These are knocked down after each run and built up fresh for the succeeding one, it having been found that repeated use, without re-building, reduced the output, owing to the walls becoming, in a measure, conducting from incrustations forming thereon. Four carbon electrodes are used at each end, their size being 2 inches in diameter by 12 inches in length. These carbons are, as in the furnace shown, adjustable lengthwise, permitting of the tightening up of their contacts with the mixture and core. The dimensions of the furnace are 18 inches in width by 12 inches in depth and 6 feet in length. The core consists of granular carbon, placed in the form of a sheet, having a width of about 10 inches, depth 1 inch, and

in length, extending the distance intervening between the electrodes, about 5½ feet.

A furnace of this construction and capacity requires from seven and one-half to eight hours' time to complete the transformation of a portion of the charge into fifty pounds of carborundum, and three of them are operated every twenty-four hours. The labor required for the preparation of the mixture, building and charging the furnace, operating and discharging the same, for twenty-four hours, consists of the services of two men and two boys. This same amount of labor would, however, be able to attend to the production of probably four times the amount now made.

From these figures and data, it will be concluded that the cost of manufacturing carborundum, on a large scale, need not exceed, and possibly not equal, the present cost of mining corundum and preparing it for the market.

Carborundum, when removed from the furnace, is a mass of crystals, of varying sizes, the greater number being of a size sufficiently small to pass through a sieve having 2,500 meshes to the square inch, and too large to pass through one having 40,000 meshes. These crystals cling together in so loose a manner that comparatively little effort is required to separate them. In the factory this separation is accomplished by throwing the crude lump material into an iron pan, and causing two heavy iron wheels to roll over it—water being introduced to facilitate the action—and the mass is stirred up continually during the grinding process.

After removal from the grinding pan, the carborundum is placed in stone tanks, and treated with dilute sulphuric acid, for a period of seven days, the object of this treatment being the removal of all iron, it having been found necessary to remove this impurity before firing in the kiln, during the manufacture of wheels, as a destruction of the crystals would result from its presence.

The intrinsic value of carborundum is a quantity yet to be determined. That it will find varied uses in the arts and manufactures cannot be doubted, its three prominent characteristics—great hardness, infusibility and incombus-

tibility—are sufficient to warrant its extensive introduction into special lines. Perhaps no other use to which it can be put will equal in importance that as an abrasive material, and should it find no other, this alone would be sufficient to class it as one of the most valuable of the materials used by the artisan. The use of emery and corundum in the form of wheels and special shapes, while of comparatively recent introduction, has grown to wonderful proportions. At no period in the world's history has the value of time been more highly appreciated than at the present day. Economy of time, increased output with a given amount of labor, and the resultant cheapening of production and consequent lower selling price of the article produced, are the demands of the times. This is being met by the manufacturer by the introduction of improved machinery and more efficient devices for rapid work and quick production. It is probable that the introduction of no other single tool into our factories, mills and shops, has produced so great a saving in labor as the emery wheel. I have not been able to obtain figures giving even an approximate value for the consumption of emery in the United States, and while I am, therefore, not prepared to say what it would actually amount to, I believe that it is several million dollars annually. These figures will convey some idea of the astonishing consumption of the material, but they will scarcely suggest the much greater amount that is, each year, saved in time and labor by its use. If emery has accomplished so much, "What," you will ask, "is left for carborundum to do?" The amount it will do and save will depend wholly upon its hardness and fitness as an abrasive, over and above these qualities as manifested in emery. The statement has frequently been made by myself and others, that carborundum was equal in hardness to the diamond, while, perhaps, a greater number of persons—who are apparently in a position to know, have stated quite the contrary—that it is not as hard as the diamond. The final determination of this important question, in a manner satisfactory to all interested parties, remains to be made. My own conclusions were arrived at from what, to me, seemed positive tests,

made without prejudice, the material having been used on diamond cutters' laps for the practical cutting and polishing of diamonds. The first test for diamond cutting was made by myself. A disc of iron was mounted in a fast running lathe, and the surface having been charged with fine carborundum crystals, a diamond contained in a ring was pressed against the revolving disc, and in from four to five minutes the facet, which had been presented to the disc, was found to be devoid of lustre, of a milky color and scored with lines. The second test was in a diamond-polishing establishment in New York. Here the proprietor was asked to re-polish the diamond above referred to, using, as the polishing agent, carborundum powder. The gentleman kindly consented to make the experiment, under the following conditions: A new lap, free from all diamond powder, should be used; my material would be tried first, and if successful, no charge would be made for the re-polishing, while if not successful, diamond powder would be substituted, and I should pay him $5 for his trouble. He added that in his opinion the $5 was just as good as earned. The new lap was mounted, and a workman supplied with one-half karat of carborundum powder, with which he was instructed to charge the lap and polish the lustreless facet. The diamond had, in the meantime been removed from its setting and mounted in lead, as is the practice in diamond polishing. Much to the surprise of the workman, the proprietor, and in some measure of myself, an application of the diamond to the lap for a period of twenty minutes removed all lines from the facet and restored it to its former beauty. Since these first tests, I have, at odd times, spent many hours in watching the operation of diamond polishing with carborundum powder, in three different diamond-polishing establishments in New York City. These various tests served to prove that the hardness of carborundum was sufficient to cut diamond surfaces – removing deep lines from them and producing a fine polish—this work being done, in the opinion of some workmen, in a shorter time than could be performed with diamond powder. They also demonstrated that carborundum was not equal to diamond powder, in

the first work of cutting the rough diamond and shaping the facet. Its failure to do this first work has been used, by some diamond cutters and others interested in diamonds and their commercial value, as a conclusive argument that it is not as hard as the diamond. While I do not wish to be understood as denying their statements, I am inclined to accept the proofs I have received with my own eyes, as conclusive evidence, that in the form of a very fine powder it compares favorably, in hardness and cutting qualities, to diamond powder of equal fineness, and to account for its failure when applied to the rougher work, it is necessary to take into consideration the brittleness of the crystals, this brittleness being, apparently, very much greater than in the case of the diamond crystal.

It is probable that methods will be worked out for reducing this brittleness, such for instance, as a process of annealing. This question, as to the exact place of carborundum in the scale of hardness, is, after all, one of scientific rather than commercial importance. Sufficient is now known to rate it very much above the abrasives ordinarily used, and as it is in the steel, iron, glass, porcelain and similar industries that the several million dollars worth of emery is yearly consumed, and not in diamond cutting, the question of first importance is, "Can carborundum be used with greater economy than emery?" To put the question in another form, "How will the cost of a given amount of work performed with carborundum compare with the cost of the same work done with emery?" We will take a case of brass valve grinding; this being a case, where owing to the metal being comparatively soft, the test will favor the softer abrasive. A number of establishments are now using carborundum powder for this class of work. In one factory they formerly used a fine emery which cost them twenty cents per pound, while the carborundum powder cost them twenty times that amount, or $4.00 per pound. The experience of months has demonstrated to them, that in the hands of a good, careful workman, one-eighth of an ounce is sufficient for one day's work, and that with such a quantity the workman

will perform not less than twice the amount of work that he could have done with any amount of emery.

The wages of the workmen are $2.50 per day. We here have, as the result of using one-eighth of an ounce of carborundum, costing six and one-fourth cents, an additional output amounting to the labor of one workman at $2.50, and assuming the emery to cost nothing, we have a value for the carborundum used of $2.43¾, and this without counting the value of the larger production turned out from the same machinery, floor space, etc. It must be admitted that this result is not attainable in all cases, for it is evident that a careless workmen could, and does, very materially reduce this saving by his wasteful use of the carborundum powder. This does not, however, change the relative values of the two abrasives, which we know it is possible to obtain. In glass cutting, tests that have been made, indicate that a given amount of work can be performed in one-fourth the time required when emery is used. Much the same conditions regarding time are found to exist in the case of carborundum on hard steel or chilled iron, and the sum of the results thus far obtained indicate an average saving of labor amounting to at least twenty-five per cent.

The value of the other two characteristics referred to—infusibility and incombustibility—as applied to industrial uses, it is at present impossible to determine. It was these qualities that made carborundum a material equal to and perhaps surpassing all others, from which to construct the small buttons used in the Tesla lamps, as shown in his lecture before the Franklin Institute last February.

The crystallographic formation of carborundum is a subject that has not received any attention at my hands, nor in the works of the Carborundum Company. I am pleased to be able to state, however, that this subject has received the attention of Professors Frazer and Richards.

The specific gravity of green carborundum crystals was found by Dr. Mulhaeuser to be 3·22.

It will be probably as interesting to you as it was at first disturbing to me, to learn that a compound, responding to

the formula SiC, has been produced by another without any known knowledge of my investigations. In the transactions of the Academy of Sciences of France (session of Monday, May 16, 1892), will be found a communication under the title, "Contribution to the History of Carbo-silicious Compounds," by Mr. P. Schützenberger. In his communication, Mr. Schützenberger described at length the manufacture of a new chemical compound of simple formula, the symbol being SiC. Briefly stated, his method was to enclose a mixture of silicon and silica in a bone-black crucible, the latter being securely covered with a lid of like material and embedded in lampblack contained in a larger crucible of graphite. This, again, was embedded in a third crucible, and the resulting nest was placed in a suitable furnace and brought up to, and held at, a high heat for some hours. Upon cooling and opening, the contained silicon was found to have been changed to a green substance and to have gained in weight an amount equal to one-half of its original weight, the silica remaining unchanged. An analysis showed the green material to be carbide of silicon with the formula SiC. No reference was made to the presence of crystals, and as it is probable the silicon used was a powder the carbide was probably, also, in the same form. The disturbed state of mind—not to specify it more definitely—which I first experienced upon learning of Mr. Schützenberger's work, was completely relieved when I found the date of his communication was three months later than the date on which Mr. Nikola Tesla exhibited a lamp containing carborundum, before the assembled scientific societies of France. The composition of what I had called carborundum was not, however, known at that date. Mr. Tesla could not state what it was, nor did any one else, to my knowledge, know that it was carbide of silicon, responding to the formula SiC.

APPENDIX.

REPORT OF AN EXAMINATION OF CRYSTALS FURNISHED BY MR. E. G. ACHESON, PRESIDENT OF THE CARBORUNDUM COMPANY.

The specimens examined were aggregations of crystals, the individual crystals, usually more or less disc shaped, varying in their largest dimensions from a fraction of a millimetre to about three millimetres. The faces were usually smooth with brilliant, adamantine lustre. The images reflected from them in the goniometer were frequently double or multiple, sometimes blurred, and sometimes broadened by diffraction. Occasionally, however, single, somewhat sharply defined, images were obtained.

The color of some of the crystals was a yellowish-green; that of others varied from a bluish-green to blue.

The crystals were found to be rhombohedral, their disc shape being due to the predominance of the basal pinacoid. The observed forms consisted of numerous direct and inverse rhombohedra, with the basal pinacoid and, in some crystals, the prism of the first order. The following rhombohedra were observed and determined, viz: $\frac{1}{5}$, $\frac{4}{5}$, $\frac{10}{11}$, 1, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{10}{7}$, 2, $\frac{5}{2}$, 4, $\frac{19}{4}$, 5, 10. No evident marks were discovered to distinguish direct from inverse rhombohedra. In one crystal, the following grouping was observed:

Direct rhombohedra.	*Inverse rhombohedra.*
1	$\frac{10}{11}$
$\frac{10}{7}$	2
$\frac{5}{2}$	5
10	$\frac{19}{4}$
	5

In some crystals, like that just described, the rhombohedral symmetry was evident; in others, the direct and inverse rhombohedra of the same parameters were found on the same crystal, so as to impart to it an appearance of holohedral hexagonal symmetry. This holohedral habit was observed in bluish-green and blue crystals, while in those yellowish-green crystals, which were examined in the goniometer, the habit was rhombohedral. Further investigation

will be needed to decide whether this coincidence is accidental or not.

The value for the length of the vertical axis was calculated from four good measurements made on three different crystals, with the following results:

$$c = 1{\cdot}2267$$
$$1{\cdot}2261$$
$$1{\cdot}2264$$
$$1.2264$$

giving the mean value, $c = 1{\cdot}2264$.

The following are a few angles between the most frequently occurring forms observed:

	Calculated.	*Observed.*
$0 \wedge \frac{10}{11}$, ...	52° 09′ 42″	52° 07½′ to 52° 14½′
$0 \wedge 1$, ...	54° 46′ 22″	54° 43¼′ to 54° 50¼′
$0 \wedge \frac{5}{4}$, ...	60° 32′ 15″	60° 32′ to 60° 46½′
$0 \wedge \frac{10}{7}$, ...	63° 41′ 49″	63° 41½′ to 63° 43¼′
$0 \wedge 2$, ...	70° 33′ 12″	70° 31′ to 70° 38′
$0 \wedge 5$, ...	74° 13′ 39″	74° 13½′ to 74° 15¾′
$0 \wedge 10$, ...	85° 57′ 39″	85° 56¾′ to 86° 02′
$1 \wedge 1$ (terminal), ...	90° 04′ 43″	
$2 \wedge 2$ (terminal), ...	109° 29′ 43″	109° 30½′

It is worthy of notice, in view of the isometric crystallization of the diamond, that the rhombohedron chosen as the unit rhombohedron has almost the shape of the cube, while the rhombohedron 2, a frequently occurring form, in combination with the basal pinacoid has very nearly the shape of the regular octahedron.

No distinct cleavage was observed.

In one instance, a twin was observed, two disc-shaped crystals being so grouped that their basal pinacoids made an angle of 109° 29′ + with each other. This would conform to the law, twinning plane, that of the unit rhombohedron.

A flat crystal examined under the microscope in converging polarized light gave the interference figure of a uniaxial mineral, thus confirming the determination of hexagonal symmetry made by measurements with the goniometer.

B. W. Frazier,

Professor of Mineralogy and Metallurgy, Lehigh University.

South Bethlehem, Pa., June 21, 1893.

The specific gravity of several grammes was determined by the specific gravity bottle as 3·123, at 25° C. = 60° F. When it was found that the blue crystals were apparently a di-morphic form of the green ones, a sample of each kind was put into a Sonstadt solution of sp. gr. 3·2, which was diluted down carefully until at a sp. gr. of 3·05, at which point the green crystal had sunk while the blue crystal still floated. It was thus evident that the blue variety has a lower specific gravity than the green.

JOSEPH W. RICHARDS.